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The Effects of Wood Adherend Species and Thickness on the Pressure Distribution along Gluelines

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Abstract

This paper deals with the pressure distribution along gluelines of bonded wood. The pressing system with a usual pressing tool of bolt clamps was discussed. The pressure distributions along gluelines were calculated using a two-dimensional finite element method (FEM). In this study we focus on the factors which affect the pressure distribution along gluelines. Three species (Douglas-fir (*Pseudotsuga menziesii ((Mirb.)) Franco*), Sugi (*Cryptomeria japonica*) and Kamerere (*Eucalyptus deglupta Bl.*)) and five thicknesses (2, 4, 6, 8, and 10 cm) of wood adherends were selected as the independent variables in numerical analysis. We hope it will be a useful reference and efficiently applied to the design of adhesion operation of wood composites. The results are summarized as follows :

1) The region where pressure was distributed decreased with the thickness of wood adherend decreasing, i. e., the thinner the wood adherend, the more non-uniform the pressure distribution along the gluelines. Pressure was concentrated under the clamp directly, and there was almost no pressure in the glueline which was distant by 1-1.5 times the adherend thickness from the clamping edge.

2) Comparison with the coniferous trees of Douglas-fir and Sugi adherends, the dicotyledonous tree of Kamerere adherends was more significant in concentration of pressure distribution.

3) An opening occurred between the adherends at the midpoint between the clamps. The height of the opening did not only depend on the flexural rigidity of the adherends, and perhaps also depended on the state of pressure distribution along the gluelines, i. e., it relied on the syntheses of flexural rigidity of adherend and the bending moment caused by pressure distribution.

Key words : pressure distribution, computer simulation, finite element method, numerical analysis, wood-based materials.

1. Introduction

Now, gluing two or more wood adherends is indispensable in producing laminated wood and other built-up wood products. Modern adhesives, processes, and techniques vary as widely as the glued-wood products made with them, also many developments have been made in recent years. Making a strong bonding with resin adhesives applied as liquids depends primarily upon a proper correlation between gluing pressure and glue consistency during pressing, because different pressing systems cause various pressure distributions along the gluelines. In the present papers[1~2], the method which could be used to simulate the pressure distribution along gluelines was developed, and a reference experiment was also performed to measure the pressure distribution along gluelines of Douglas-fir adherends by a pressure-sensitive film. The results showed a qualitative agreement between these two, so the efficiency of the analytical method could be assured. However, this study

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is continue to clarify the effects of wood adherend species and thickness on the pressure distribution along gluelines. The computer simulation with a two dimensional finite element method was used, and the independent variables discussed in this paper include three species (Douglas-fir (*Pseudotsuga menziesii ((Mirb.)) Franco*), Sugi (*Cryptomeria japonica*) and Kamerere (*Eucalyptus deglupta Bl.*)) and five different thicknesses (2, 4, 6, 8, and 10 cm) of wood adherends.

All computations were performed on a FACOM 780/10Q Computer of Kumamoto University Information Processing Center.

2. Analytical method

The upper part of Fig. 1 is a schematic diagram showing the bolt clamp-pressing system of two-wood adherends without caul plate. The distance between the clamps was extremely great compared to the thickness of the adherends. The pressure distribution along glueline and core gap behavior were calculated by computer simulation. It was assumed that the glueline was so thin and had almost no effect on the mechanical behavior of whole pressing system. The analysis was performed on the idealized model shown in the lower part of Fig. 1. It was obtained by means of fictitious cut through only a quarter of the whole pressing system due to symmetrical pressing condition. This quarter part is approximated by a finite element mesh consisting of eight hundred 3-node plane stress triangular elements with appropriate loading and boundary conditions.

The mechanical properties of three species wood adherends[3~4] are shown in Table 1. All of the wood adherends were approximately assumed to be the orthotropic elastic materials. These were in edge grain, so x is the direction in longitudinal, and y is the direction in tangential of wood adherends.

The boundary conditions of this analytical method are described as follows:

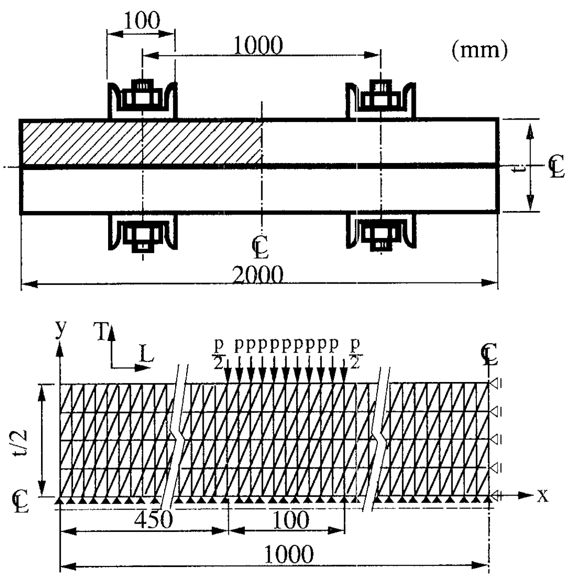

Fig. 1 Finite element idealization for 1/4 part of the pressing system.
Legends: p: Linear load; t/2: Thickness of wood adherend.

Table 1 Elastic constants of wood adherends.

Elastic constants	Ex	Ey	Gxy	μxy
	10^3kgf/cm^2			
Sugi	75.0	3.00	3.50	0.60
Kamerere	99.7	3.98	1.47	0.45
Douglas-fir	160	8.00	9.00	0.45

Notes: Ex: Young's Modulus parallel to grain; Ey: Young's Modulus perpendicular to grain; Gxy: Modulus of rigidity; μxy: Poission's ratio.

At the beginning of calculation, all the nodes on the center line in thickness direction (correspond to the glueline) were simply supported and only with freedom in x direction. The nodes on the center line in longitudinal direction were constrained in x direction but with slide hinges in y direction. In order to simulate the gap behavior along glueline, calculation was iterated to determine the boundary conditions step by step, i. e., where the vertical nodal force of the node that is along glueline shows downward, the node there must be released in y direction with next calculation step. This process is necessary to describe the none pressure or gaped portion along the glueline. Finally, when the reaction forces of all the constrained nodes in y direction show positive, the calculation was stopped.

The loading condition as shown in the lower part of Fig. 1 will be described in the following. For simplicity the external pressure forced on adherend by the bolt-clamp, the uniformly distributed load (10 kgf/cm^2) in the downward direction is considered to be imposing on the nodal points where the bolt-clamp and adherend contacted with (10 cm). The adherend was thought as in unit width of 1 cm. Therefore the total external force is 200 kgf. As the total length of adherend is 200cm, the average pressure along glueline is 1 kgf/cm^2, just as the unit pressure.

3. Results and discussion

3.1 The effects of wood adherend species and thickness on the pressure distribution along gluelines

A comparison of pressure distribution along gluelines among three species and five thicknesses of wood adherends was shown in Fig. 2. All the curve of pressure variation are bell-shaped symmetrical with respect to the vertical line through its peak, i. e., the maximum pressure occurred directly below the clamp and the pressure decreased rapidly with the increasing of the distance from

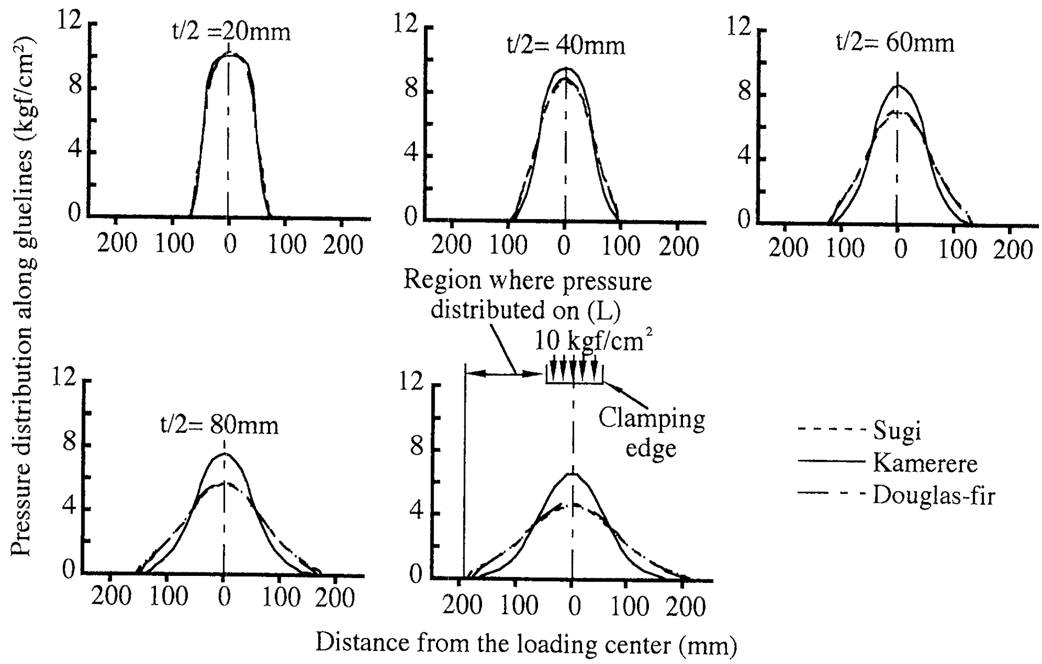

Fig. 2 Comparison of pressure distribution.
Note : t/2 : Thickness of adherend.

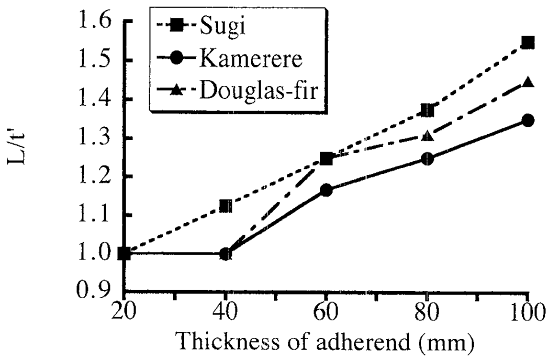

Fig. 3 Comparison of the region where pressure distributed on.

Notes : L : The region where pressure distributed on from the clamping edge ; t′ : t/2, Thickness of adherend.

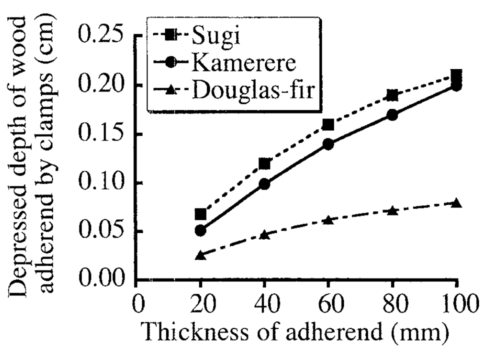

Fig. 4 Deformation of wood adherend under clamp in different thicknesses and species.

the clamp. These are in accord with the theory discussed by S. P. Timoshenko and J. N. Goodier[5]. According to their theory, the vertical stress decreases as an inverse power of the distance from the point of the loading. So pressure distributed were concentrated in a narrower region directly under the clamp, and the concentration was more significant in the case of thinner rather than thicker adherend. The region where pressure was distributed was positively correlated with the thickness of wood adherends. This means that pressure along glueline of thicker adherend is distributed more uniformly than that of thinner one. There was almost no pressure in the glueline distant by 1.0–1.5 times the adherend thickness from the clamping edge (see Fig. 3). This could be very helpful in designing the suitable pressing system for wood adhesion.

Exception of 20 mm thick adherend, the effects of wood species on pressure distribution was clear. The pressure deviation are almost the same between two coniferous tree wood adherends of Douglas-fir and Sugi. These were different from the dicotyledonous tree wood adherend of Kamerere. It is clear that the pressure distribution of Kamerere adherend was more non-uniform. It was due to the orthotropic property of wood adherend in elastic constant. Although there is a large difference of elastic modulus between two coniferous wood adherends of Douglas-fir and Sugi, the norms which respect their orthotropic property, the ratio of elastic constant (E_x : E_y : G_{xy}), are almost the same. The pressure distribution about these two are well-matched. Comparing these two, Kamerere adherend has the lowest shearing stiffness, i. e., it has a different orthotropic property from them, so the pressure transmission maybe weakened because of its large shearing deformation.

3.2 The relationship between deformation of wood adherends and pressure distribution

The effects of species and thicknesses of wood adherends on deformation was very clear (Fig. 4). The depressed depth of wood adherend by bolt clamp depends on the modulus of elasticity in pressed direction. Sugi showed the biggest, then Kamerere, and lastly the Douglas-fir.

An opening occurred between the adherends at the midpoint between the clamps (Fig. 5). As discussed before, there is almost no differences of 20 mm thick adherend on pressure distribution along glueline in different species of wood adherends. Therefore, in this case, height of the opening only depends on the flexural rigidity of the adherends. However, when the differences of pressure distribution exist (exception of the thinnest wood adherend of 20 mm), the core gap height does not

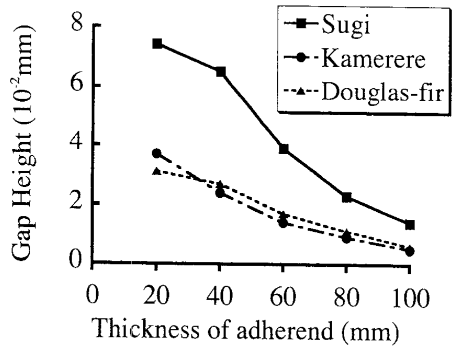

Fig. 5 Comparison of gaps between adherends at the midpoints between clamps.

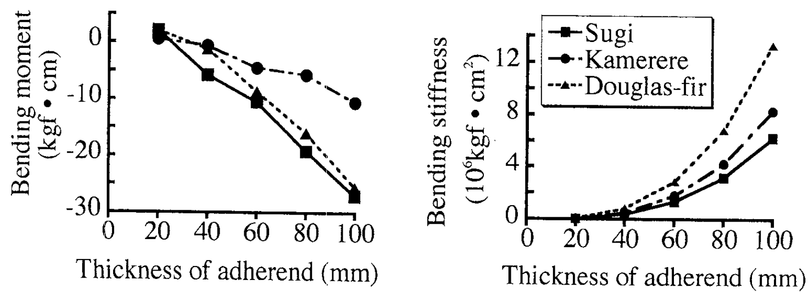

Fig. 6 Comparison of bending moment and bending stiffness in different adherends.

only depend on the flexural rigidity of the adherends but also depends on the state of pressure distribution along glueline, i. e., it relies on the syntheses of flexural rigidity of adherend and the bending moment caused by pressure distribution (refer to Fig. 6).

4. Conclusions

The quantitative analysis of pressure distribution along gluelines was discussed. The independent variables include three species levels and five thickness levels of wood adherends. The results could be summarized as follows :

1) The region where pressure was distributed decreased with the thickness of wood adherend decreasing, i. e., the thinner the wood adherend, the more non-uniform the pressure distribution along the gluelines. Pressure was concentrated directly under the clamp. There was almost no pressure in the glueline distant by 1-1.5 times the adherend thickness from the clamping edge.

2) Compared with the coniferous trees of Douglas-fir and Sugi adherends, the concentration of pressure distribution along the gluelines was more significant in the case of the dicotyledonous tree of Kamerere adherends were used.

3) An opening occurred between the adherends at the midpoint between the clamps. The height of the opening did not only depend on the flexural rigidity of the adherends, and perhaps also depended on the state of pressure distribution along glueline, i. e., it relied on the syntheses of flexural rigidity of adherend and the bending moment caused by pressure distribution.

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